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TECHNICAL MEMORANDUM

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TITLE: DIMENSIONAL CHANGE OF STELLITE 6B DURING PHASE TRANSFORMATION FROM FACE-CENTERED CUBIC TO HEXAGONAL CLOSE-PACKED CRYSTAL STRUCTURE

ABSTRACT

The linear dimensional contraction of Stellite 6B due to transformation from the face-centered cubic to the hexagonal close-packed crystal structure was determined on 18 parts using 91 individual measurements. The average contraction and the standard deviation of the 91 individual measurements were determined to be 0.092% and 0.042%, respectively.

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INTRODUCTION

Stellite 6B* is a high-temperature cobalt base alloy which exhibits excellent mercury erosion resistance and good mercury corrosion resistance. Therefore, it was selected and employed as the reference SNAP-8 turbine rotor and nozzle material. It was subsequently determined that at the turbine operating temperatures (700-1238°F) this alloy, in the forms employed in the turbine, transforms from a face centered cubic (FCC) to a hexagonal close packed (HCP) crystal structure. This transformation was produced in the laboratory by thermally treating Stellite 6B for 4 hours at 1650°F followed by 48 hours at 1250°F. The change in structure is accompanied by a volumetric contraction of the material. Therefore, machined parts of Stellite 6B in the FCC condition undergo a reduction in linear dimensions when transformed to the HCP condition. To determine the extent of this contraction and its effect on drawing tolerance requirements, various samples and actual parts were dimensionally inspected before and after the transformation and the data were analyzed statistically.

TEST PROCEDURE AND RESULTS

Various laboratory samples prepared from forgings and bar stock, and thirty-seven actual TA parts were transformed using the laboratory thermal treatment (see Table I). Ninety-one individual linear dimensional measurements were made before and after transformation on eighteen of the pieces. The number of dimensions obtained on each piece was dependent on the configuration at the part being inspected. The laboratory samples were primarily thin, narrow rectangular specimens and only the longest dimension was inspected in two locations. On actual circular parts, however, several dimensions at different circumferential locations around the periphery of the pieces were obtained. The calculated average contraction and standard deviation were 0.092 and 0.042%, respectively (see Table II and Figure 1). Based on these data and on the assumption that a normal distribution exists, there is a 99% probability that 99% of the measured contractions due to the crystallographic

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* 30Cr - 4.5W - 1.1C - 3 max Ni - 2 max Si - 3 max Fe - 2 max Mn - 1.5 max Mo

transformation of Stellite 6B will fall between 0% and 0.223% (see Figure 2).

Based on a plot of the individual data points (Figure 1) the assumption of normal distribution is essentially true, but the curve stops at 0% contraction because of the physical impossibility of growth occurring during the transformation from FCC to HCP. This impossibility exists because the HCP structure forms from rearrangement of the same number of atoms as the original FCC structure but in a more dense population or smaller interatomic spacing pattern. The more densely packed atoms cannot produce a larger volume of metal. The data (Table II) indicate that a significantly greater variation exists between specimens than within individual specimens. This is demonstrated by the standard deviations of 0.030% and 0.075% for variability within and between specimens respectively, and by the 6.4 F ratio obtained. An F ratio this large would be obtained less than one time in a thousand if the specimens were all being randomly selected from a homogeneous population. The large variation in contraction, both within and between specimens, remains unexplained at present. However, it is thought that anisotropy and possibly residual stress patterns may influence the dimensional changes which occur. The literature indicates investigators have found that the linear contraction of pure cobalt due to transformation lies between 0.08 and 0.12%. This relatively wide variation also has not been explained but it has been theorized that anisotropy and impurities may influence the contraction.

CONCLUSIONS

1. The crystallographic transformation of Stellite 6B from a FCC to a HCP crystal structure is accompanied by a volumetric contraction of the alloy.

2. The mean linear contraction and standard deviation on data from 18 specimens are 0.092% and 0.042%, respectively.

3. There is a significantly greater variation in contraction between specimens than within individual specimens.

4. The actual amount of contraction which will occur on a specific part cannot be predicted with enough accuracy to permit the transformation to be performed on a finish machined part for the turbine unless wider than presently desirable tolerances are allowed.

RECOMMENDATIONS

1. Stellite 6B parts should be transformed to the HCP condition prior to the final machining operation whenever possible to eliminate the effect of contraction variability on part tolerance.

2. The anticipated range of linear contraction, 0.000% to 0.223%, should be examined in relation to specific parts which have been finish machined prior to the transformation to the HCP condition to determine if the anticipated contraction is acceptable.

3. Further dimensional contraction data in three axes should be obtained on Stellite 6B parts which are to be transformed. This will improve the statistical understanding of the phenomena and could indicate if anisotropy contributes to the variation in contraction.

TABLE I

SPECIMEN DISCRIPTIONS

Specimen No.	Name	Part Dimension Measured (in.)*	
		Maximum	Minimum
1	First-Stage Rotor	5.4504	1.0028
2	Nozzle Diaphragm Assembly	6.2052	1.7473
3	Nozzle Diaphragm Assembly	6.2063	1.7474
4	Nozzle Diaphragm Assembly	6.2060	1.7474
5	Nozzle Diaphragm Assembly	6.4070	1.7472
6	Nozzle Diaphragm Assembly	6.4071	1.7479
7	Nozzle Diaphragm Assembly	6.4064	1.7476
8	Nozzle Diaphragm Assembly	6.2053	1.7475
9	Nozzle Diaphragm Assembly	6.4067	1.7475
10	Laboratory Specimen	2.1294	
11	Laboratory Specimen	2.1180	
12	Laboratory Specimen	2.2098	
13	Laboratory Specimen	2.2090	
14	Laboratory Specimen	2.3110	
15	Laboratory Specimen	2.3.43	
16	Laboratory Specimen	2.1982	
17	Laboratory Specimen	2.0563	
18	Fourth-Stage Diaphragm	5.5848	1.7476

* All dimensions were read to the nearest 0.0001 inch. The estimated error in reading, therefore, is $\pm$ .005% for the smallest dimension, 1.0028, and $\pm$ 0.0008% for the largest dimension, 6.4071.

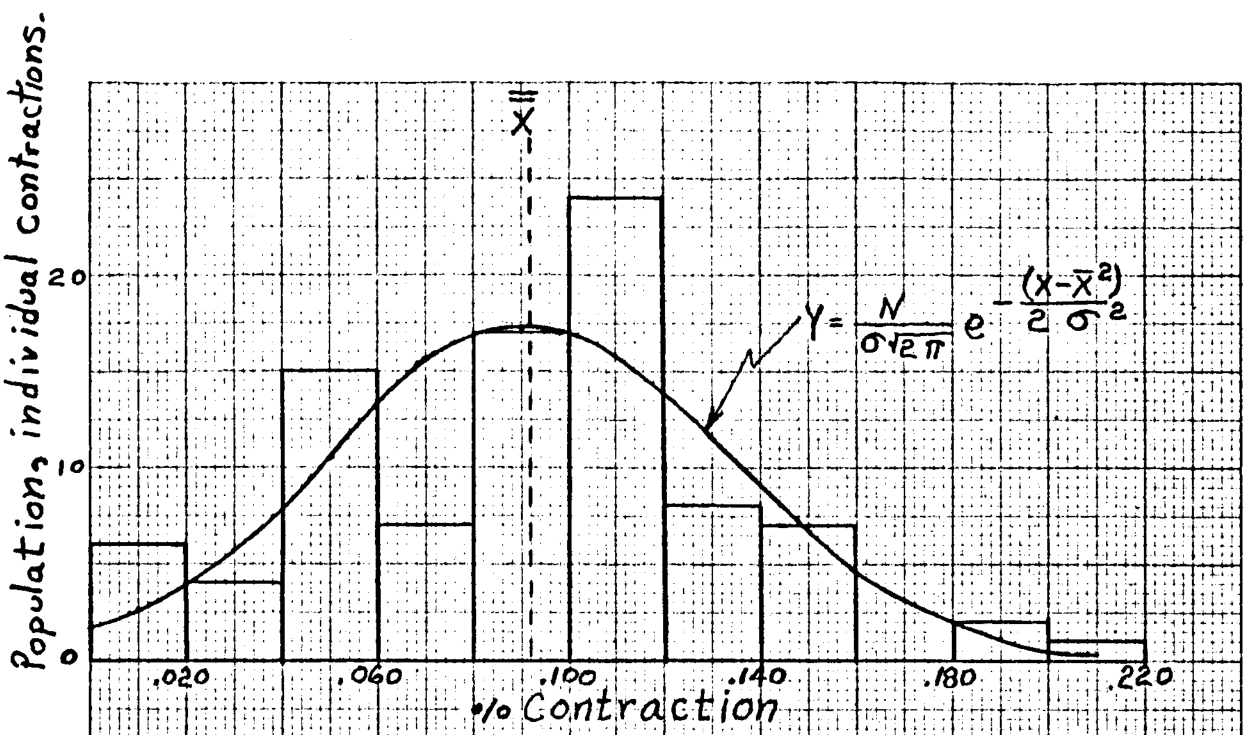
TABLE II

ANALYSIS OF CONTRACTION OF STELLITE 6B IN TRANSFORMING FROM FCC TO HCP CRYSTAL STRUCTURE

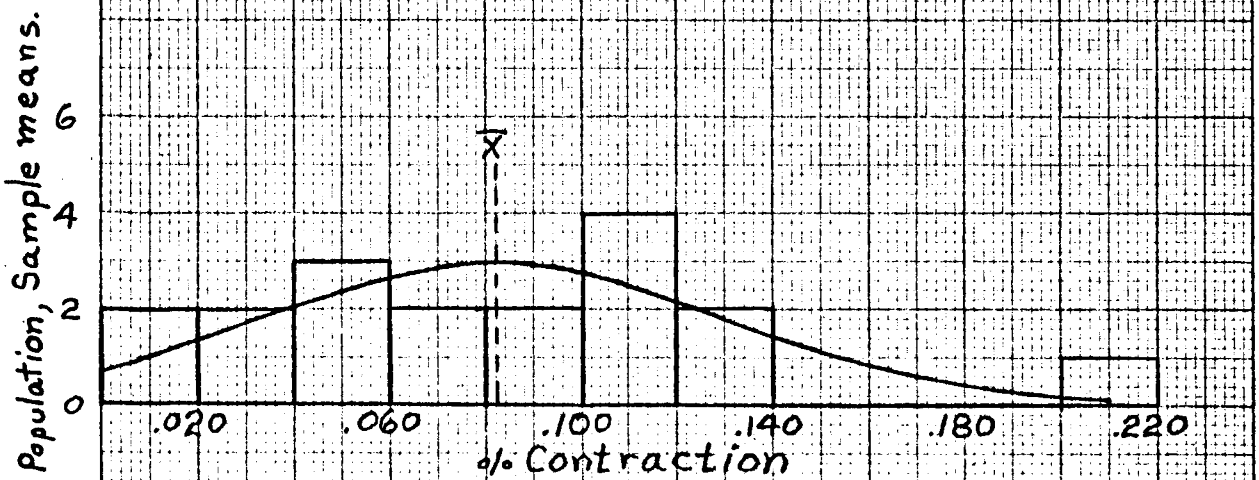
Specimen No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Totals
% Contraction	.055	.110	.100	.100	.106	.116	.081	.134	.066	.023	.048	.019	.059	.017	.118	.210	.048	.015	
	.055	.084	.120	.111	.112	.101	.069	.145	.039	.000	.053	.052	.054	.052	.027				
	.057	.106	.110	.016	.070	.125	.059	.148	.200										
	.057	.129	.116	.133	.062	.095	.058	.131	.195										
	.067	.108	.097	.097	.086	.125	.120	.111											
	.082	.097	.137	.143	.109	.109	.109	.149											
	.077	.111	.097	.098	.092	.133	.110	.118											
	.082	.097	.143	.143	.109	.109	.109	.149											
	.044																		
	.022																		
	.051																		
	.000																		
	.080																		
	.100																		
	.120																		
	.090																		
ΣX	1.039	.842	.920	.841	.746	.913	.715	1.085	.500	.023	.101	.071	.113	.069	.145	.210	.048	.015	8.396
$(\Sigma X)^2$	1.079521	.708964	.846400	.707281	.556516	.833569	.511225	1.177225	.250000	.000529	.010201	.005041	.012769	.004761	.021025	.044100	.002304	.000225	6.771656
n	16	8	8	8	8	8	8	8	4	2	2	2	2	2	2	1	1	1	91
$(\Sigma X)^2/n$	.067470	.088620	.105800	.088410	.069564	.104196	.063903	.147153	.062500	.000264	.005101	.002520	.006384	.002380	.010512	.044100	.002304	.000225	.871406
ΣX^2	.080335	.089836	.107992	.100177	.072146	.105383	.068429	.148693	.083902	.000529	.005113	.003065	.006397	.002993	.014653	.044100	.002304	.000225	.936272
$\Sigma X^2 - (\Sigma X)^2/n$	.012865	.001216	.002192	.011767	.002582	.001187	.004526	.001540	.021402	.000264	.000012	.000544	.000012	.000612	.004140	0	0	0	.064861
$\overline{X}$	.065	.105	.115	.105	.093	.114	.089	.136	.125	.012	.050	.036	.057	.034	.072	.210	.048	.015	1.481

Source of Variation	Sum of Squares of Deviation	Degrees of Freedom	Mean Square	Standard Deviation	F Ratio
Between Specimens	.096765	17	.005692	.075%	6.4*
Within Specimens	.064861	73	.000889	.030%	$\overline{\overline{X}}$ = .092%
Total	.161626	90	.001796	.042%	$\overline{X}_{means}$ = .082%

* $P\,(F = 6.4_{df_1=17,\ df_2=73}) < .001$ ∴ Variation between specimens is concluded to be significantly greater than variation within specimens.



a- Gaussian curve calculated from data and fitted to histogram of individual contractions, standard deviation = 0.042 %



b- Gaussian curve calculated from the sample means and fitted to a histogram of mean contractions, standard deviation = 0.049 %

Fig. I Distribution of contraction which occurs during the transformation of Stellite 6B from the FCC to the HCP crystal structure.

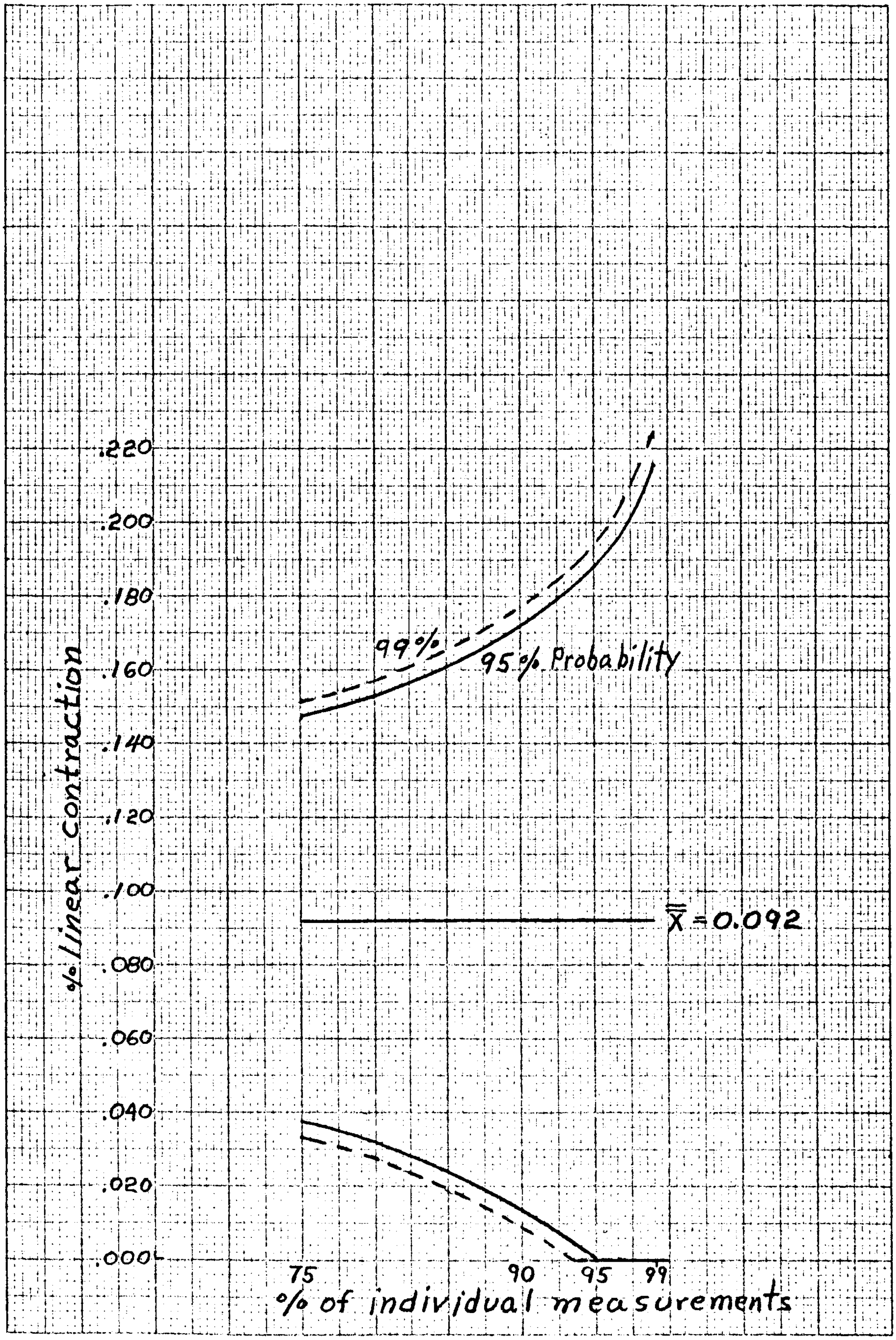


Fig. 2. Probability of individual contractions falling within specific tolerances.

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